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Truss-type shear connector for composite steel-concrete beams

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HIGHLIGHTS

- Experimental and numerical tests of new connector, the Truss Type shear connector.
- Truss-Type connector (TT-connector) cross section area is equivalent to 19 mm stud-bolt.
- In push out-out tests, TT-connector showed more resistance than the 19 mm stud bolt.
- The tests showed TT-connector has good ductility and stress distribution.
- TT-connector may be used when the equipment for stud-bolt application is unavailable.

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ABSTRACT

Shear connectors are important in composite steel-concrete beams. This work presents a new connector, named truss-type shear connector. This connector is an alternative to replace stud bolt in special situation. The connector's geometry was conceived aiming at low cost, easy execution, high resistance, and efficiency concerning slipping and uplift. Six specimens were constructed for push-out tests comparing this alternative connector with stud bolts. The behavior of the specimens was investigated for collapse, slipping and uplift. Experimental results were compared against numerical FE simulation showing good agreement and providing a global view of the truss-type shear connector behavior and its viability.

1. Introduction

The economic, technical, and scientific developments in the construction industry have brought about a great number of structural systems. Among them, steel-concrete composite structures have proved to be efficient from the structural and constructive points of view. As for the structural aspect, one can emphasize the better usage of materials' resistance properties, effectively exploring in a better way the potentials of concrete and steel [1]. The resulting combination of steel and concrete in composite beams, for example, provides lighter but more resistant structures. The use of composite structures with all its structural efficiency advantages [2] should be encouraged for bridge construction and even made more popular for medium and small construction too. As for the constructive aspect, steel-concrete beams can be built faster than reinforced concrete beams as the steel beam helps as support along the concrete slab curing process. Therefore, steel-concrete beams use less wood forms to cast the concrete slab. To accelerate even more the constructive process in making composite beams, precast concrete slabs can be associated with steel I-beam sections. Today, with increasing demand for infrastructures and dwelling, steel-concrete beam is a fast and cost effective system that may be well used for multi-story buildings and bridges.

The efficiency of steel-concrete beams, as resisting structure, depends highly to the interaction between two key structural elements: (a) steel I-beam and (b) overlaid concrete slab. Effective links between concrete slab and steel profile are required because these two materials have to act as a unique structure. Steel connectors are used as shear connectors, and, generally, they are welded to the steel profile flange and merged into the concrete slab – even though other options are available today [3].

One important characteristic for a shear connector in composite beams is its ductility. Shear connector may be classified in two categories depending of its ductility: rigid or flexible. Rigid connectors do not deform much under service load. They can provide good connection without showing much relative slipping displacement between steel I-beam and concrete slab. However, the collapse of rigid connectors is brittle. In this case, concrete failures for shear or crushing, and brittle failure takes place. Generally, such collapse

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is instantaneous showing no previous warning signals – which is not desirable for structural safety reasons. On the contrary, flexible connectors deform much more under load, allowing large relative slipping displacement between steel and concrete parts. This type of connector presents ductile collapse showing previous signs of breakdown. Flexible connectors are not quite good for some loading situations like oscillating loads. During an earthquake, shear connectors are subjected to reverse cyclic loading and flexible connectors deform more than rigid connectors, accordingly, they are more susceptible to early collapse. One example is the traditional headed stud bolt which is known to be a flexible connector and in this situation its strength is 17% lower [4]. Studs deform under service loads and have low performance under alternative loads, generally, breaking due to fatigue [4]. Rigid connectors, on the contrary, are not likely to go under early fatigue problem. For composite steel-concrete beams, the ideal shear connector should present very small slip displacement, rigid behavior, between steel and concrete when the composite beam is under service loads. However, the ideal shear connector should also present ductility at ultimate limit state. For an ideal shear connector, the characteristic of rigid connector is desirable for service load, and the characteristic of flexible connectors is sought in the ultimate limit state.

For the classification of shear connector as rigid or ductility, a criterion commonly accepted today is defined by the European Standard EN 1994-1-1: 2004 [5] for composite structures. The criterion is based on the characteristic slipping that each connector type may present, and this characteristic slipping can be measured in standard push-out tests.

The most commonly used shear connector today is the headed stud, or stud bolt [6,7]. This fact was mainly due to the productivity and the ease way such connector can be applied. The stud bolt is conceived to work as an arc welding electrode and it can be applied directly to the steel I-beam flange, or even over the metal sheeting of the steel decking over the steel I-beam flange. As a result of the high degree of automation and practicability in the construction site, the stud bolt is the connector commonly used all over the world. One disadvantage in the use of stud bolt is when the composite structure is submitted to fatigue. Besides, for the application of this type of connector, specific welding equipment and high electric power, approximately 225 kVA generators, at the construction site are needed. These requirements limit the application of stud bolt connectors [3]. Moreover, there are also some problems involving the performance of stud connectors and their installation [8]. One problem is the reliability of the installation automation of the welding process. Another problem is the relatively small load that each stud bolt can withstand. Therefore, in steel-concrete composite beam, a large number of studs have to be applied. There are several other parameters that influence stud connectors like the shank diameter, the height of the stud, the bedding height, among others [9,10].

In the context of some countries, the installation of studs carries additional concerns, like the difficult to get the special welding machine and enough electric power in remote construction site. The appropriate welding machines have high cost and difficult acquisition for small construction companies operating in isolated areas away from large urban centers. Depending on the location of the construction site, the need for extra energy generator and a good energy infrastructure can make steel-concrete composite structures more expensive, if stud bolts are used. Therefore, the choice of the connector type, their correct size, and their execution are of great importance – since they determine the good or bad interaction degree, and the ways stresses are distributed, between the two materials, i.e. steel and concrete.

There are many recent researches on new types of shear connectors that could substitute the traditional stud bolt [11]. There are alternative shear connectors applied with welds, bolts and nuts, and even connectors that may be assembled and disassembled (i.e. mountable and demountable connectors). Recently, alternative connectors have deserved more attention in the technical literature with many motivations and a wide variety of ideas and gadgets presented [11–14].

This research shows a new type of alternative connector, the Truss-Type (TT) Shear connectors made of common steel type CA-50 bars – commonly used in reinforced concrete structures. The geometry of the alternative TT connector was conceived targeting: (a) no need for special equipment for the installation of the connector, (b) low cost of production, (c) easy installation and execution, (d) high resistant value, (e) efficiency concerning relative slip and uplift resistances between steel section profile and concrete slab. The approach of numerical and experimental studies is of great value to understand the behavior of the proposed alternative TT connector. This approach is considered in this research.

2. Conception of the truss-type connector

The shear connectors designed for this research were built using steel rebar type CA-50 for reinforced concrete structures and bent in triangular shape with geometry as illustrated in Fig. 1. In that figure, for bending downwards, the concrete slab and the steel I-beam flange act, respectively, as the top and bottom chords of a truss, and the legs of the TT connector are like truss diagonal elements. These observations are important to explain the name given to this connector: Truss-Type (TT) shear connector. The goal in developing TT shear connector is also to get an alternative connector that could be used in situations where the use of stud bolts is not possible. The TT shear connector here presented has been registered in the Brazilian National Institute of Industrial Property under the number: BR302016002949-0. Alternative connectors must be well studied in order to become reliable for engineering practice. Studs are already well acknowledged by many Standards, including the European Code EN 1994-1:2004 [5] and the AISC Code [15], among others, but new options of shear connectors are always welcome. Therefore, for the experimental comparison between TT connectors, 19 mm (3/4") diameter and, approximately, 130 mm (5 3/16") height stud bolts were used.

For the assembly of the TT connector, CA-50 bar with 1/2" (12.5 mm) diameter which is very mush used in civil construction was chosen. The reason for 12.5 mm diameter is to approximate the cross section area of the two legs of the TT connector to the cross section area of the 19 mm stud bolt. The two legs of the TT connectors substitute one stud bolt with 19 mm. Comparing the steel cross section area of the Stud Bolt with 19 mm diameter (SB-19.0) and TT connector with 12.5 mm diameter (TT-12.5), it can be seen that the cross section area of the SB-19.0 is $A_{SB} = 2.84\ cm^2$ and the cross section area of the two legs of the TT-12.5 (see Fig. 1) is $A_{TT} = 2 \times 1.27 \approx 2.53\ cm^2$. Therefore, both connectors are about the same, even though $A_{SB}/A_{TT} \approx 1.12$, or A_{SB} has 12% more cross section area than the two legs of the TT connector.

With respect to the mechanical properties, CA-50 steel bar for TT-12.5 has yielding stress of 595.3 MPa and ultimate stress of 716.6 MPa, while SB-19.0 presents a yielding stress of 345 MPa and ultimate stress of 415 MPa. TT-12.5 mm and SB-19 mm connectors are about the same height, respectively, with 130 mm (see Fig. 1). For the TT connector, a piece of 40 mm in length was welded to the top angle (see Fig. 1) of each connector to resist the uplift. Such piece plays an analogous role as the stud-bolt head. The link between the truss connector and the steel profile was made with butt welds applied on both end sides of the TT connector legs welded to the steel I-beam flange (see Fig. 1). Shielded Metal Arc Welding (SMAW) was applied with E70 electrodes. Each of the four weld strings (at each side of the TT connector legs) was executed with 35 mm of length (see Fig. 1). For the push-out tests